STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF FACILITIES CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

THE CONSTRUCTION AND INITIAL EVALUATION OF SULFUR EXTENDED ASPHALT (SEA) PAVEMENT IN A HOT CLIMATE (INTERIM REPORT I)

Study Supervised by .... R. N. Doty, P. E.

Principal Investigators .... G. R. Kemp, P. E. and
R. D. Smith, P. E.

Co-Investigator .... N. H. Predoehl
and R. Reese, P. E.

Report Prepared by .... N. H. Predoehl

RAYMOND A. FORSYTH, P.E.
Chief, Office of Transportation Laboratory

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16. ABSTRACT

Caltrans placed its first SEA test section in the northbound lanes of I-15 (Road 8-SBd-15-107.75/110.0) between Barstow and Baker, California, during September 1982. The test section consisted of an AR-2000 control, SEA 20% and 40% sections, and the AR-4000 job asphalt. The test sections range from 1/2 to 1 mile in length. This report covers the design, installation, and first and second year evaluation of these test sections. The installation involved preblending of the sulfur and asphalt with the Texas Gulf apparutus, mixing in a drum mixer, and conventional paving procedures. The initial findings revealed few problems regarding mix design, mixing temperature control, paving, compacting, and environmental controls. Various field and laboratory tests indicated that the SEA materials and pavements reacted similarly to the control materials and pavements. Condition and crack surveys 11, 17, and 22 months after installation showed that the SEA and control pavements were both in excellent condition with no cracking in any of the sections.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second 1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

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INTRODUCTION

Sulfur extended asphalt (SEA) experimental projects have been installed at many locations in the United States and Canada over the last several years (1 thru 9). Most of these projects were involved primarily with the technology of designing and installing a sulfurized asphalt roadway. They have generally proven that SEA pavements are a viable alternative to conventional asphalt concrete (AC) pavements.

The California Department of Transportation (Caltrans), in conjunction with the FHWA, started a sulfurized asphalt research study in 1981 with three stated objectives:

1. Determine whether one grade of "soft" asphalt can be used in both cold and hot areas (with the addition of sulfur to change the characteristics of the resulting mixture so that the needs of both climates could be met with the one soft asphalt product),

2. Determine the durability of the resulting SEA pavement in each environment, and

3. Develop laboratory test procedures which will predict SEA mixture field performance.

In order to achieve these goals, two sets of test sections, one in a hot area and the other in a cold area, have been placed. This report describes the planning, installation and field and laboratory testing of the hot-climate SEA and "control" (conventional) AC test sections.

Two SEA blends, 20 and 40 percent,* were used in the project plus the "blending" control asphalt (AR-2000) and the "job" control asphalt (AR-4000). (Sections containing the additive "ChemCrete" (Figure 2) were also placed in this project, but they are not documented in this report.) Included are data from the California Tilt Oven Durability (CATOD) test (California Test 374) which may provide a means to estimate the weathering characteristics of the various binders used in the test sections.

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*All sulfur percents shown are "by weight" of total binder.

FINDINGS AND CONCLUSIONS

Since this report deals primarily with the planning and installation of the SEA hot climate test sections, the findings and conclusions listed below apply to those aspects of SEA.

1. Designing the SEA mixes presented no problems other than compensating for the differing specific gravities of asphalt and sulfur.

2. The use of dry sulfur in the mix design provides a more positive method of controlling sulfur quantities than using a preblended sulfur-asphalt mixture.

3. Monitoring of the percent sulfur during the mixing process was effectively done using calculations involving specific gravities of the various sulfur-asphalt blends (at the appropriate mixing temperatures) and the specific gravity, via hydrometer, of the sulfur-asphalt blend going into the mixer. (This only works where the asphalt and sulfur are preblended prior to entering the mixer.)

4. Proper heating and insulation of valves and piping is vitally important in the storage, blending, and piping of sulfur and sulfur-asphalt blends at the mixing plant.

5. Conventional mixing, paving, and compaction operations are virtually unaffected by the use of SEA binder.

6. No environmental problems occurred regarding the generation of H_2S or SO_2 gases at the mixing or paving sites because of good temperature control in the mixing process.

7. Measurements at the mixing and paving sites revealed that particulate concentrations are variable and subject to wind and availability of fines. No significant concentrations of free sulfur developed at the mixing or paving sites.

8. Varying weather conditions during the SEA paving revealed that SEA mixes are quite forgiving of windy, cool, and damp-weather paving conditions.

9. Tests measuring skid resistance, deflection, and ride quality of the completed SEA pavements revealed no significant differences between the SEA and control pavements.

10. Test data on samples from the windrow indicate insignificant differences in mix properties between the control and SEA mixes.

11. Test data on binders sampled at the hot plant and on recovered binder from windrow samples revealed that the addition of sulfur generally reduced the viscosity of the binder below that of the AR-2000 control binder.

12. The hot extraction procedure (Calif. Test 310) is capable of accurately indicating the amount of total SEA binder in a SEA mix.

13. For both the 20% and 40% SEA blends, tests of SEA binders recovered by the Abson process indicate that approximately 20 percent of the sulfur goes into solution with the asphalt.

14. Condition and crack surveys 11, 17, and 22 months after installation revealed no cracking in either the SEA or control test areas. All sections were in excellent condition.

15. Test data for core samples removed ten (10) months after construction indicate similar whole-core physical properties for the control and SEA samples, except that the SEA 40% samples had slightly lower surface abrasion losses.

16. Test data on binders recovered from cores removed ten (10) months after construction show a slight hardening pattern for all the binders but no inconsistencies in the weathering patterns of the SEA and control binders.

IMPLEMENTATION

Since this report deals with the initiation of the SEA program in only one climatic area, it would be premature to recommend any actions based on the present information.

TEST SECTION

I. Location

The hot climate field trial of SEA binders was incorporated into a large overlay project on Interstate 15 about 25 miles southwest of Baker, California and about 35 miles northeast of Barstow, California in San Bernardino County (Figure 1). The test sections are located in the north-bound lanes near the southwest end of the 38 mile-long rehabilitation project. Figure 2 shows the precise locations of the various test sections. The test site is in the Mojave Desert at an elevation of approximately 1700 feet and was selected because it, of the available projects, most closely fit the desired climatic conditions. The climatic conditions of the site consist of hot dry summers (July and August average maximum temperatures of approximately 100°F) and cool dry winters (December and January average minimum temperature of approximately 30°F) with a yearly average temperature of 63°F. Precipitation averages approximately four inches per year according to U. S. Department of Interior Geological Survey charts for the test area. The test section location was selected because of its generally straight and level alignment and because of its fairly uniform pavement condition.

II. Roadbed Design and Condition

The roadbed upon which the test areas were placed was constructed in 1964 and included 0.04 feet open-graded asphalt concrete (OGAC), 0.54 feet dense-graded AC, 0.67 feet aggregate base (AB), and 0.75 feet aggregate subbase (AS). Figure 3 shows the typical cross sections and thicknesses used in the overlays. Prior to placing any overlays, the OGAC layer was removed.

Figure 1

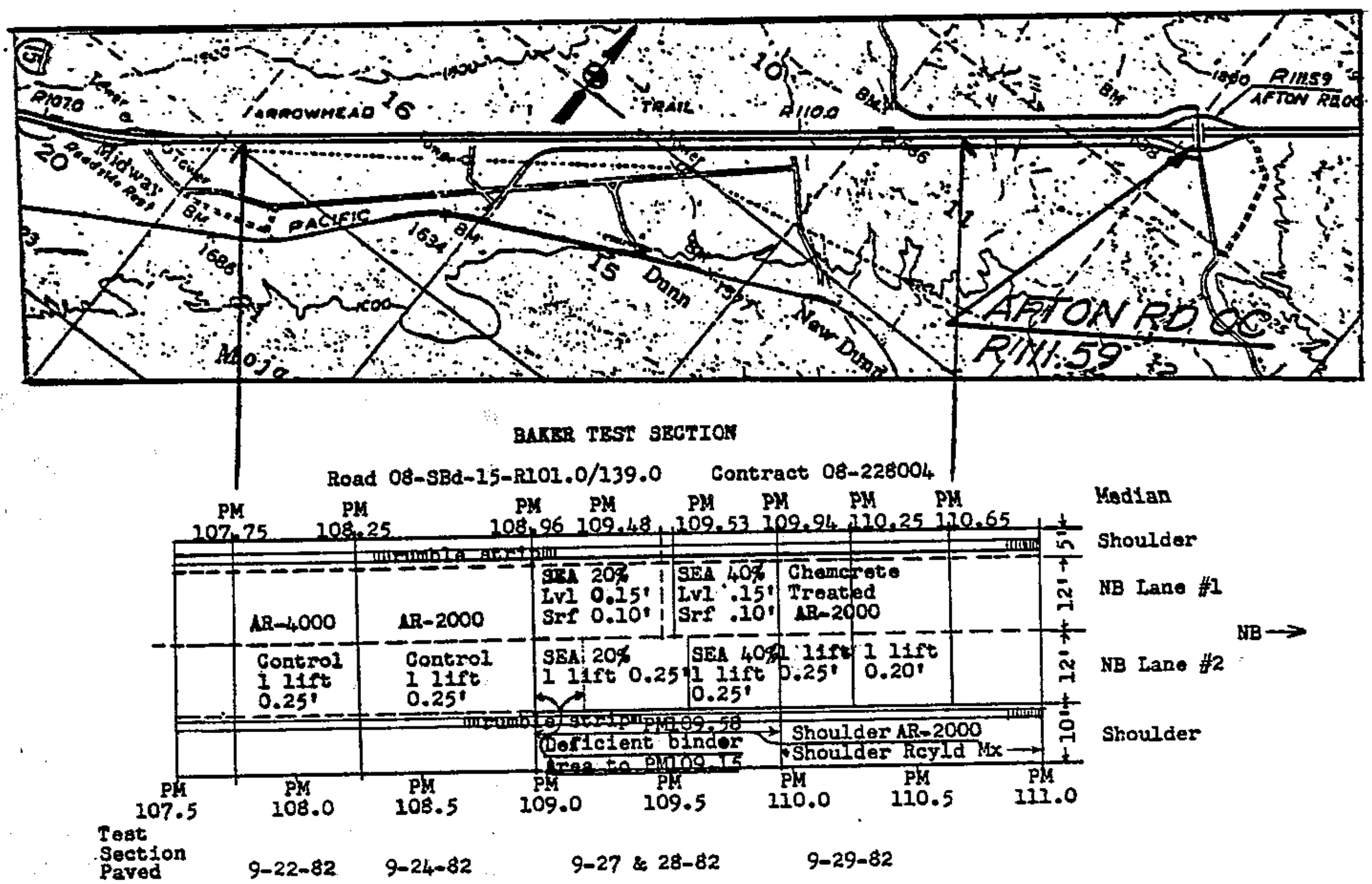
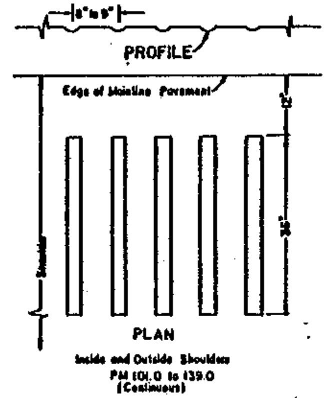


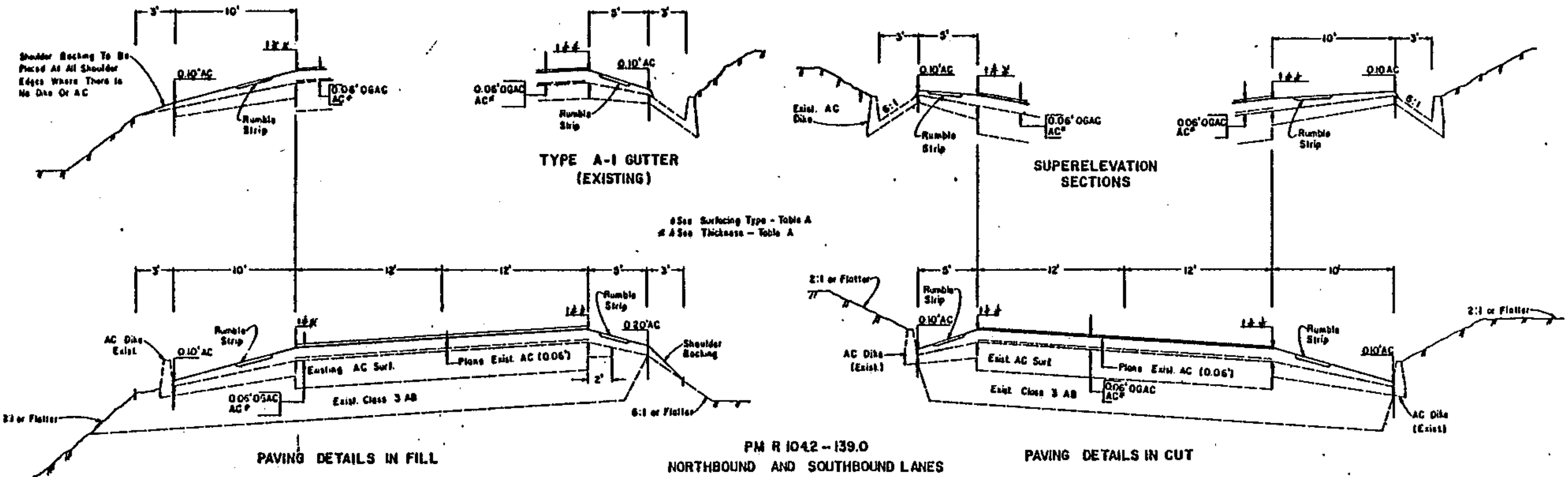
Figure 2

TABLE A

POST MILE (R)	NB	SB	THICKNESS (1)	SURFACING TYPE	OPEN GRADED AC YES	OPEN GRADED AC NO
104.20 - 107.75	x		0.20'	ASPHALT CONCRETE (TYPE A)	x	
107.75 - 108.25	x		0.25'	ASPHALT CONCRETE (TYPE A)		x
108.25 - 108.75	x		0.25'	ASPHALT CONCRETE (20% SULFUR)		x
108.75 - 109.25	x		0.25'	ASPHALT CONCRETE (40% SULFUR)		x
109.25 - 109.50	x		0.25'	ASPHALT CONCRETE (CHEM-CRETE) AR-2000		x
109.50 - 109.75	x		0.20'	ASPHALT CONCRETE (CHEM-CRETE) AR-2000		x
109.75 - 110.25	x		0.25'	ASPHALT CONCRETE (TYPE A) AR-2000		x
110.25 - 138.80	x		0.20'	ASPHALT CONCRETE (TYPE A)	x	
104.20 - 128.00		x	0.20'	ASPHALT CONCRETE (TYPE A)	x	
128.00 - 130.30		x	0.25'	ASPHALT CONCRETE (TYPE A)	x	
130.30 - 138.80		x	0.20'	ASPHALT CONCRETE (TYPE A)	x	



RUMBLE STRIP



PM R 104.2 – 139.0
NORTHBOUND AND SOUTHBOUND LANES

TYPICAL CROSS SECTIONS

SCALE: 1" = 1' VERTICAL
1" = 4' HORIZONTAL

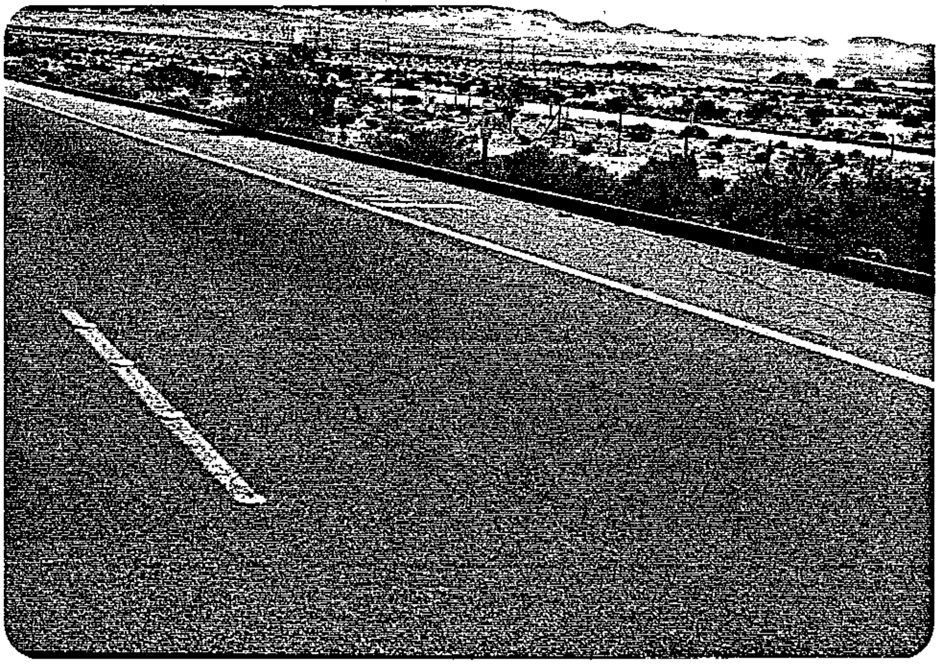
Figure 3

The condition of the roadway surface throughout most of the project was one of extensive alligator cracking, plus transverse and longitudinal cracking. Figure 4 shows examples of the typical condition of the test section area. A detailed crack survey was made prior to the test section installation. Preinstallation equivalent deflection measurements via the Dynaflect ranged from 0.001" to 0.020".

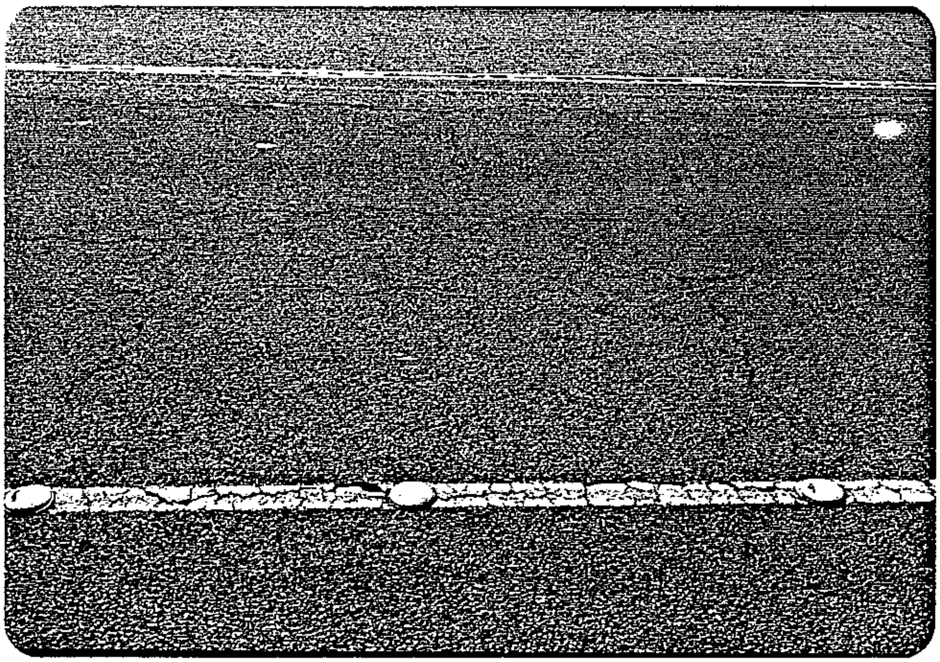
Since the road is the main route between Los Angeles and Las Vegas, it receives heavy traffic at all times. Traffic data indicated a 1979 ADT of 15,300 vehicles per day and a 1995 predicted ADT of 26,000. Truck traffic accounts for 15% of the ADT and the estimated 10-year Traffic Index is 11.5.

PREINSTALLATION LABORATORY INVESTIGATION

Prior to beginning the SEA mix design, a quantity of the asphalt, sulfur, and aggregate that would be used in the project was obtained. SEA blends, using the proposed asphalt, were made in 10 percent increments between 0 and 50 percent sulfur (by weight of total binder) so that the specific gravity could be obtained at about 280°F for each blend. A graph (Figure 5) was then prepared at several temperatures within the mixing range of the SEA binder. This graph, showing specific gravity vs percent sulfur at various temperatures, enabled determination of sulfur content at the mixing plant by means of a hydrometer and thermometer. From the experience obtained in preparing these SEA blends and from the difficulties encountered in testing the higher sulfur content blends (because of sulfur "fallout"), it was determined that using preblended SEA binder in the mix design process would not be very successful. Therefore, a special mix design procedure



North View at PM 109.0 NBL



View Across Lane At PM 108.95 NBL

Figure 4

Preinstallation Views before removal of OGAC prior to installation of overlays. Views are in area where SEA 20% pavement is located.

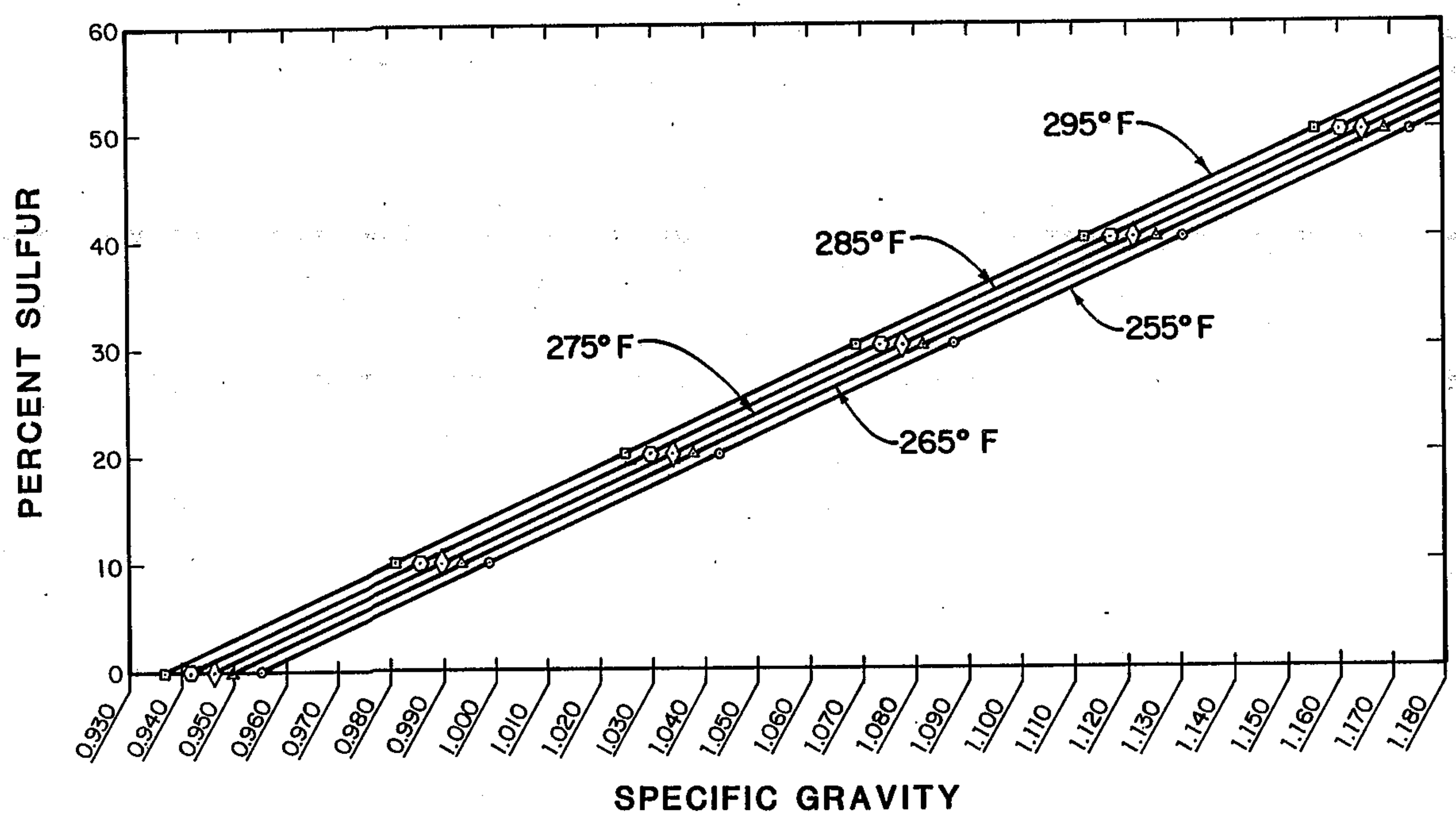


Fig. 5. CALCULATED SPECIFIC GRAVITIES (RELATIVE DENSITY) OF SEA BLENDS.

incorporating powdered sulfur was formulated. This procedure insured that the percentage of sulfur in the SEA design mix would be correct. Mix design information for the test sections is presented below:

Design Method: Calif. Test 367 (Hveem)
Mix type, size, and grading: Type A, 1/2" max., coarse.
Aggregate: From Opah Ditch Pit

Properties:
Specific gravity - Fine: 2.69, Coarse: 2.56
LART Abrasion loss = 5% (100 revolutions)
= 26% (500 revolutions)
Kc = 1.2, Kf = 1.1, Km = 1.1
Sand equivalent value = 64
Surface area = 26 Ft^2/LB

Asphalt: AR-2000 (Newhall)
Binders: Straight AR-2000, SEA 20%, SEA 40%
Sulfur: Commercial grade (99.9% pure), powdered
Temperatures: Aggregate 300°F, Binder 300°F
Mixing procedure: Using carefully weighed quantities, add asphalt to aggregate, pour into mixer and add powdered sulfur to mix as it starts mixing. Mix until completely coated and smell of sulfur is strong, indicating that the sulfur has melted.

Design Binder Content Data:

	Binder %	Design Briquette Values		
Binder	Wt.	Hveem Stab.	Voids %	Sp. Gr.
AR-2000	5.4	40	6.0	2.25
SEA 20%	6.0	41	6.0	2.26
SEA 40%	8.0	38	4.5	2.27

It should be noted that since only about one-half of the sulfur goes into solution in the SEA 40% mix, the remainder acts as a filler, thereby necessitating a larger volume of binder to obtain proper mix properties. The AR-4000 job AC mix was designed by the District laboratory.

Marshall Test Results Of Laboratory Mixes Having Actual Binder Contents Used In The Field:

Binder	Binder Content (%)	Stability (lbs)	Flow (0.01 in.)	Sp.Gr.
Control (AR-2000)	5.2	1473	23	2.28
SEA 20 %	6.0	1840	21	2.32
SEA 40 %	8.0	2617	23	2.35

TEST SECTION CONSTRUCTION

The construction of the test sections was part of an ongoing contract that did not commence until late in September, 1982.

I. Hot Plant and Aggregate Source

The hot plant used for the project was a CMI dryer-drum unit which turned out about 400 tons of AC mix per hour. The plant was located at the Opah Ditch Pit about one mile north of the roadway (P.M. 126.87). This is about 10 miles west of Baker, California. The haul distance to the test sections was 18 to 20 miles. For the SEA blending operation, the contractor enlisted the services of Texas-Gulf, which has a portable blender and storage tank unit which can be tied into a hot plant operation. Figure 6 shows views of the hot plant complex and the sulfur unit with connecting piping.

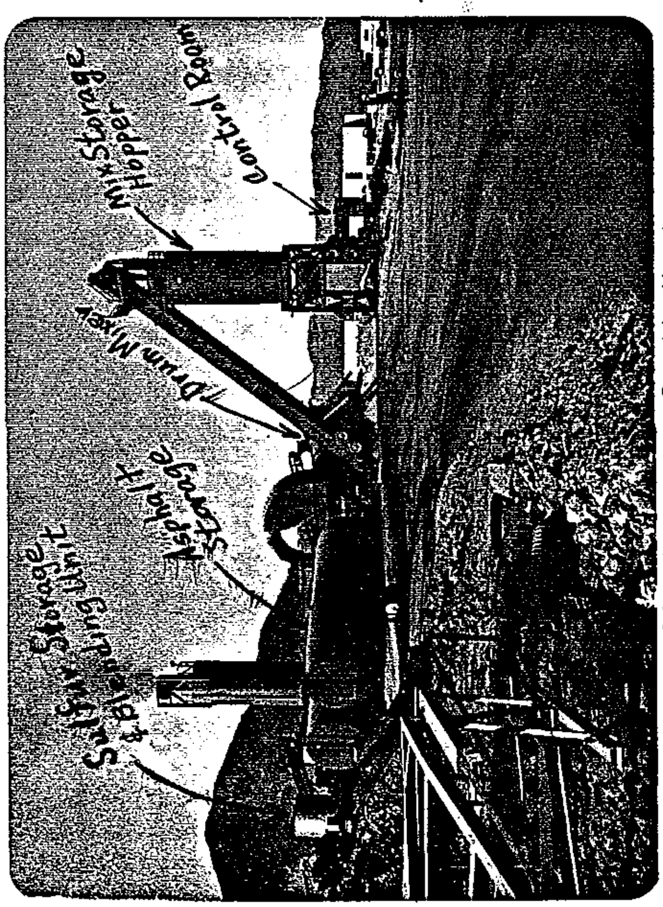
The liquid sulfur was shipped in insulated trailers from a refinery in the Los Angeles area and then pumped into the heated storage tank of the Texas-Gulf unit. An in-line static mixer blended the asphalt and sulfur prior to piping the blended binder to the dryer-drum mixer. No changes were made in the location of the binder inlet pipe in the drum mixer.

II. Installation

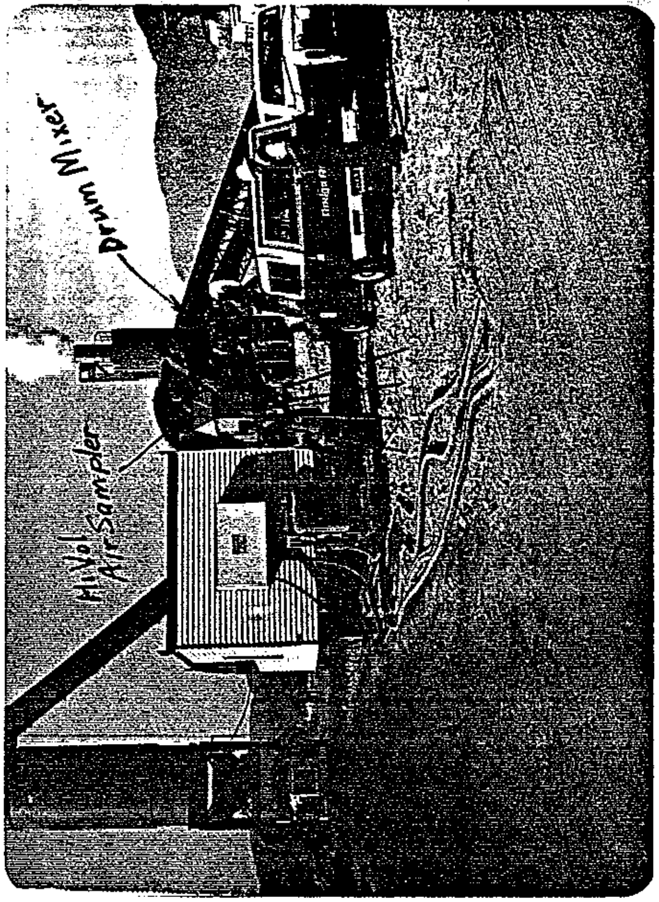
A. Control Sections

The construction of the test sections began on Wednesday, September 22, 1982, with the "job" asphalt (AR-4000) control sections (Figure 2). Table 1 gives dates, locations, thicknesses, and paving details concerning mix temperatures and weather conditions for the various test sections. The weather conditions for the AR-4000 control were excellent and the plant and paving operation ran perfectly.

The SEA paving was to begin the next morning. The weather was warm (90 to 100°F high) and clear, but the sulfur blender would not operate. The blender was plugged and would not function properly until another heater was installed to raise the temperature of the circulating oil line. By 12:30 p.m., it was decided that no SEA paving would occur on Thursday or Friday so the contractor decided to pave the AR-2000 control section while unplugging efforts continued on the sulfur blending unit. It was still hot on Friday (but cloudy) and the AR-2000 control was placed without problems.

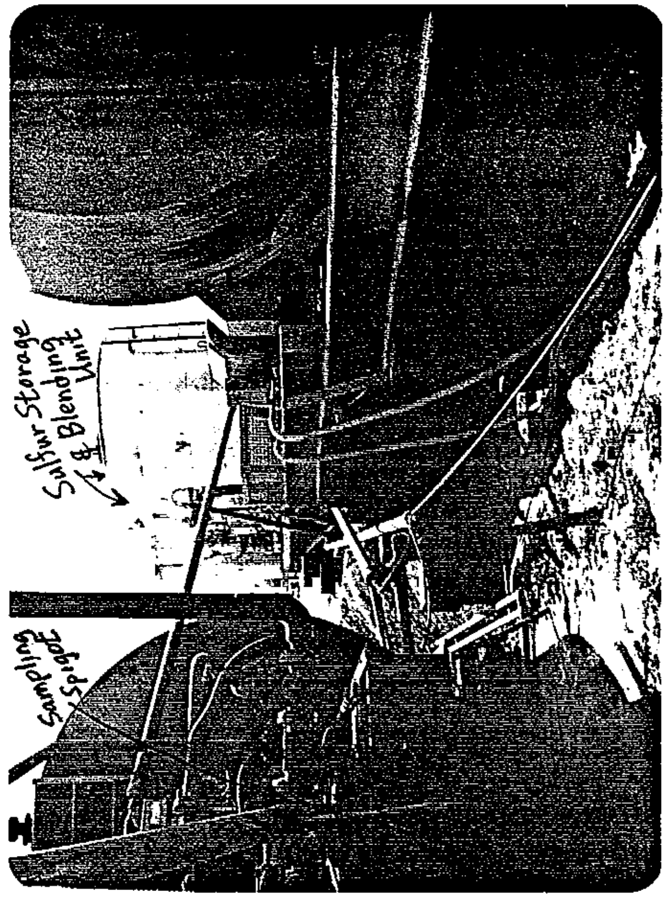


Overall View From South West



View From East- Note HiVol Air Sampler

Texas-Gulf Sulfur Tanks & Blending Unit



Piping & Sampling Spigot

Figure 6 Mix Plant Views

TABLE 1

BAKER TEST SECTION INSTALLATION

Paving Dates, Conditions, and Details

Date	Section (% Binder)	Location PM	Location Lane	Thickness	Mix Temperatures (°F Avg.) Plant	Windrow	Laydown	Breakdown	Weather (°F) AM Temp	PM Temp
9-22-82	AR-4000 (5.4%)	107.75/ 108.25	#1 &#2	0.25' (one lift)	282	271	252	233	Clr 83/ 98	Clr 98/ 103
9-24-82	AR-2000 (5.2%)	108.25/ 108.96	#1 &#2	0.25' (one lift)	285	270	243	242	Cldy 83/ 100	
9-27-82	SEA 20% (6.0%)	108.96/ 109.48	#1	0.15' (level course)	286	284	247		Clr 68/ Wndy	Cldy 77
	SEA 20% (4.2%)	108.96/ 109.15	#2 (deficient binder area)	0.25'	286	278	247		Cldy 77 Wndy	
	SEA 20% (6.0%)	109.15/ 109.58	#2	0.25' (one lift)	286	278	247			Cldy Shwrs 78
	SEA 40% (8.0%)	109.48/ 109.94	#1	0.15' (level course)	287	274	252	245	Cldy 78 Wndy	
	SEA 40% (8.0%)	109.58/ 109.94	#2	0.25' (one lift)	287	274	252	245		Cldy Shwrs 78
9-28-82	SEA 20% (6.0%)	108.96/ 109.53	#1	0.10' (surface course).	286	278	275	265	Clr 73/ 82	
	SEA 40% (8.0%)	109.53/ 109.94	#1	0.10' (surface course)	287	278	275	265	Clr 82	

Over the weekend, the Texas-Gulf people and the contractor finally got the sulfur blending operation running smoothly, and on Monday, September 27, the SEA paving operation began. Over the weekend, however, the weather had changed. Monday morning (9-27-82) was mostly clear, but quite cool (77°F high) and windy. It appeared to be satisfactory weather for paving although not as warm as desired.

B. SEA Sections

The SEA mixing and paving started smoothly with the mix plant providing good control of the mix temperatures throughout the paving operations (Table 1). Mixing temperatures were controlled to between 270 and 300°F during the SEA mixing. Specific gravity tests were determined at the plant with a hydrometer on the hot SEA binder in one gallon paint cans. The results matched the expected specific gravity for the percent sulfur from the prepared graph. (Figure 5)

Paving with the SEA mixtures began at P.M. 108.96 in the northbound No. 1 lane at about 8 a.m. Due to poor communication, adverse weather conditions, plant problems, etc., five different SEA test areas were placed by the time the SEA paving was finished. All of the sections were to have been placed in one lift, but a mix-up caused the paving of the SEA in lane 1 in two lifts. Figure 7 provides a summary of the chain of events involved in the SEA paving operation. The five SEA test areas may be categorized as follows:

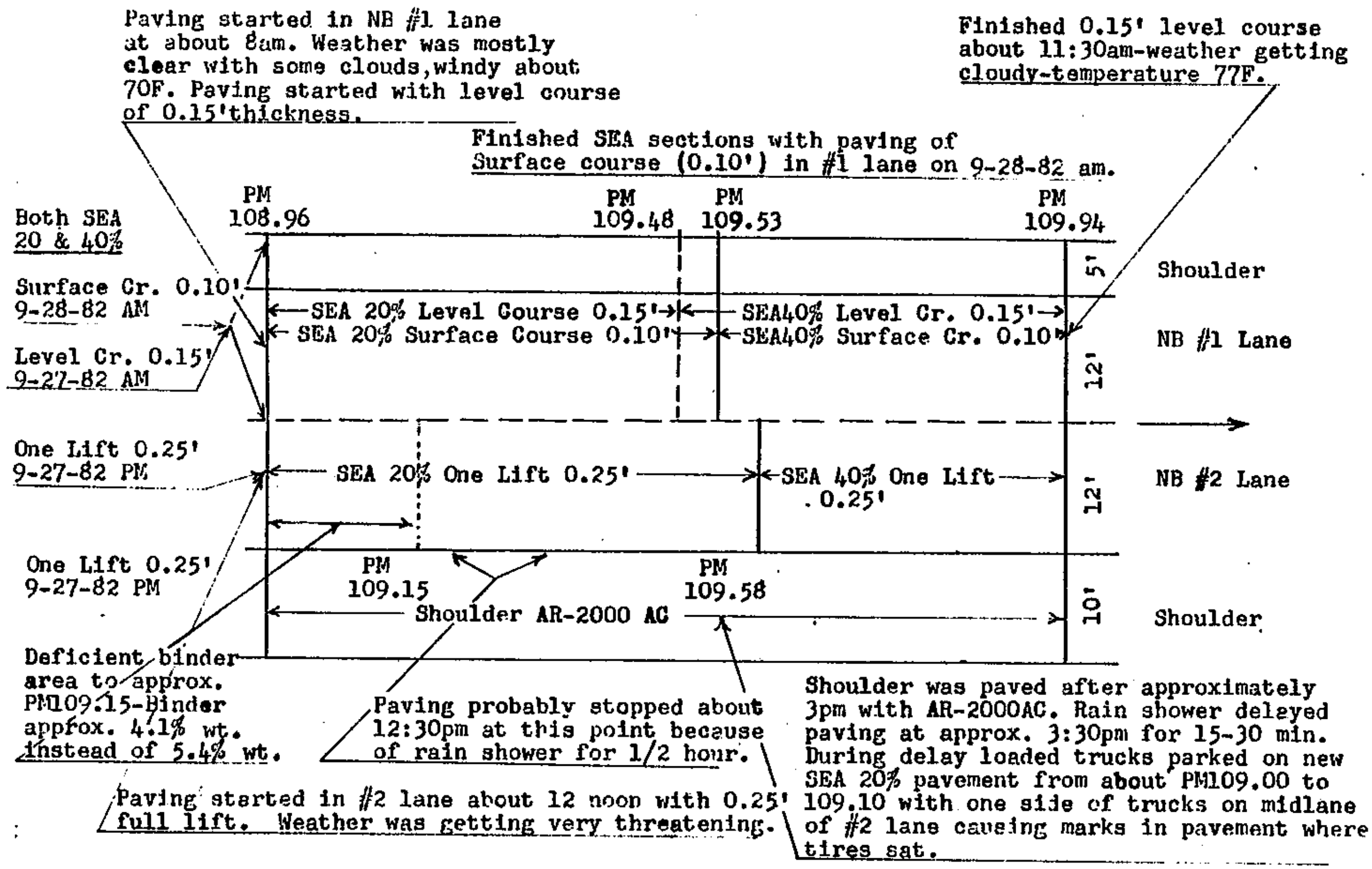


Figure 7

Test Section Paving Sequence Map

	Section	Location	Lane	No. of Layers	Thickness	Actual Binder Content %
1.	SEA 20%	PM 108.96-109.53	#1	2	0.10' Surf 0.15' Level	5.5
2.	SEA 40%	PM 109.53-109.94	#1	2	0.10' Surf 0.15' Level	7.9
3.	SEA 20%	PM 108.96-109.15	#2	1	0.25' one lift	4.2
4.	SEA 20%	PM 109.15-109.58	#2	1	0.25' one lift	5.5
5.	SEA 40%	PM 109.58-109.94	#2	1	0.25' one lift	7.9

Generally, the paving operation with the SEA material was no different than that with the conventional AC. Mix and paving temperatures were very similar to those used on the control sections. (See Table 1). Generally, the breakdown temperatures were close to the State of California specified 250°F minimum breakdown temperature. The paving train consisted of a Barber-Green paver with a CMI windrow loader. The rolling procedure used was the same as that used on the rest of the contract; this consisted of breakdown with a Dynapac CC21A (7 ton) vibratory roller and a second pass with a Dynapac CC42A (11 ton) roller without the vibratory operation. Finish rolling was with the Dynapac CC21A in the nonvibratory mode.

The compaction specification for this contract was to be a trial-end result specification using nuclear densities to determine compliance to a relative compaction requirement of 95%. Due to a provision in the method that the thickness of the lift had to be at least 0.15', the nuclear density was not always run. No nuclear densities were run during the placement of the test sections even though the lifts met the minimum thickness provision. Even though the compaction specification was not followed precisely, the compaction met the 95% relative compaction as later determined from core densities on cores taken 10 months after construction (Table 14).

The rolling of the SEA material did not appear to be plagued with any setting or tenderness problems although it appeared that the breakdown roller was "hanging back" a little compared to the conventional asphalt mixes. No complaints were heard from the roller operators regarding the rolling. Figures 8 and 9 portray the paving equipment and SEA paving operation. Of interest is a specially modified roller for rolling a "rumble strip" into the fresh mix in the shoulder areas.

C. Environmental Measurements

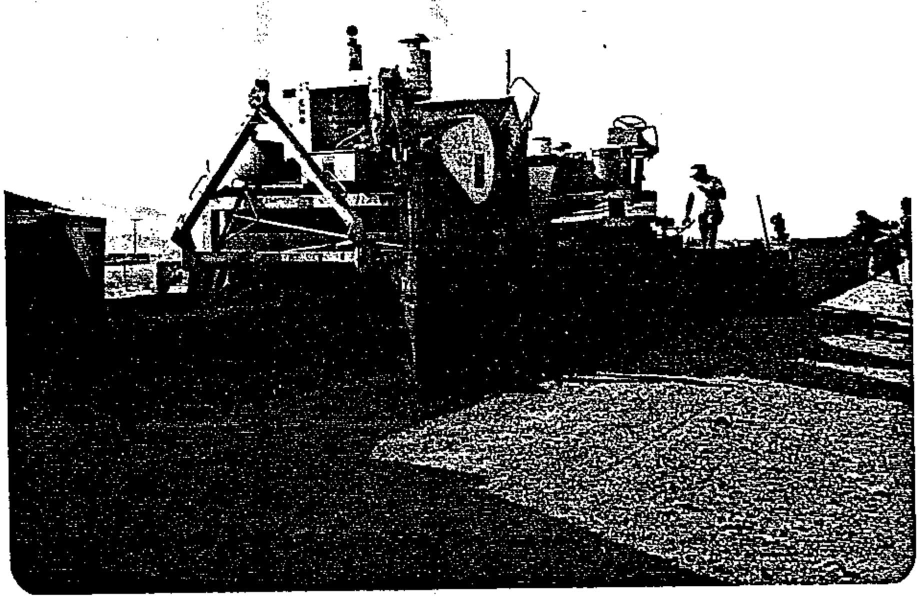
Since hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) gases are the most likely undesirable by-products during the production of SEA mixtures, measurements were made of the levels of airborne H_2S and SO_2 vapors at the plant site and on the street during the SEA paving operation. Table 2 summarizes the toxic effects of different levels of H_2S and SO_2. In addition, total suspended particulate levels were measured to see what amounts of free sulfur and sulfates were present during the SEA paving operation. The measuring devices used to determine the levels of these pollutants consisted of:

1. Short-term exposure devices:

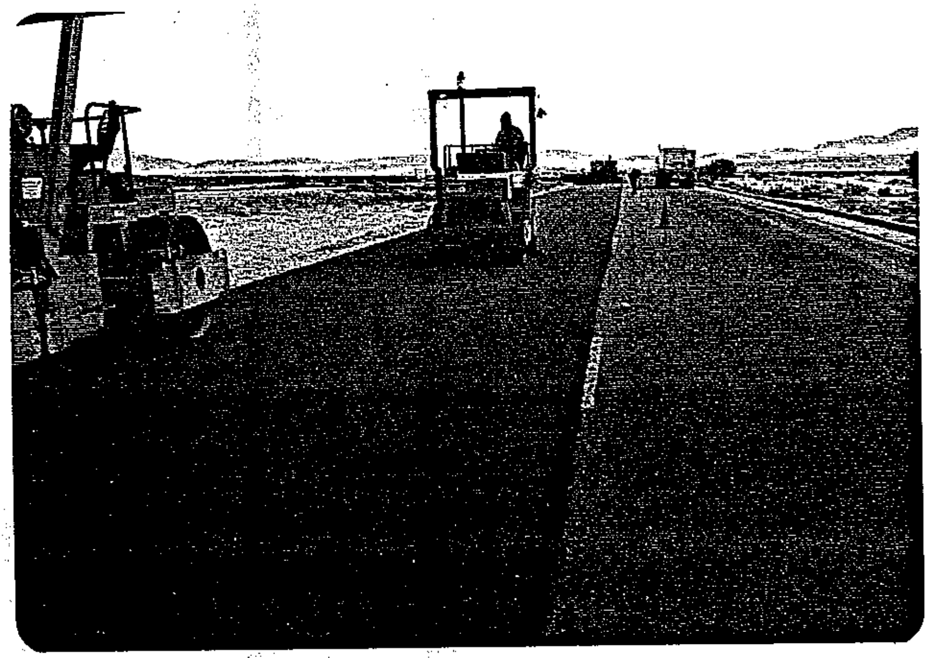
    a. H_2S - Interscan Model 1176 Portable Gas

Figure 8

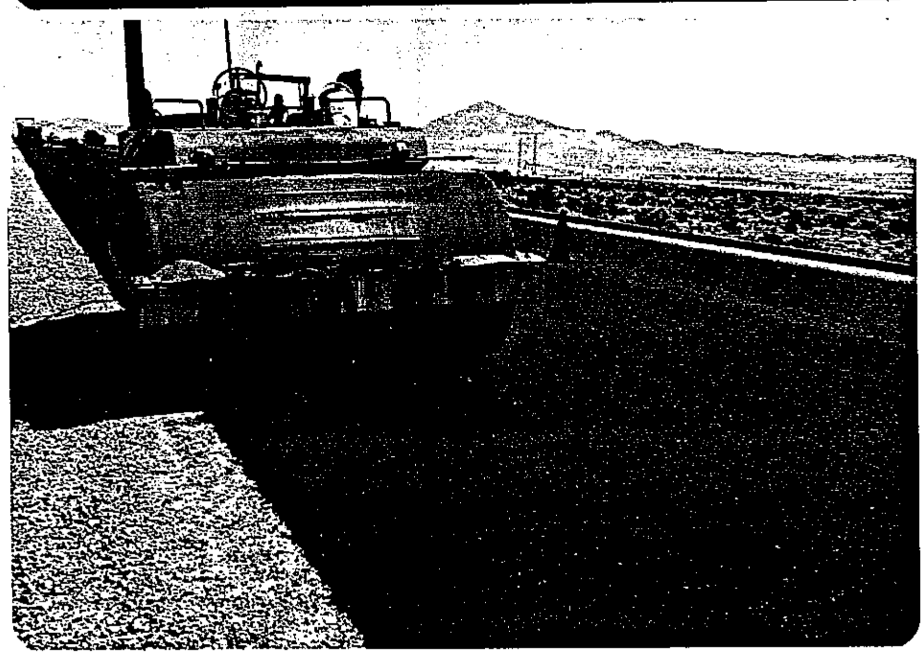
Paving Equipment used on SEA Test Section.



Barber-Green Paver and CMI Windrow Loader



Dynapac Vibratory Rollers- Vibratory for breakdown and nonvibratory for finish rolling.



Specially modified Hyster roller for rolling in "Rumble" strip in new mix on shoulder edges.

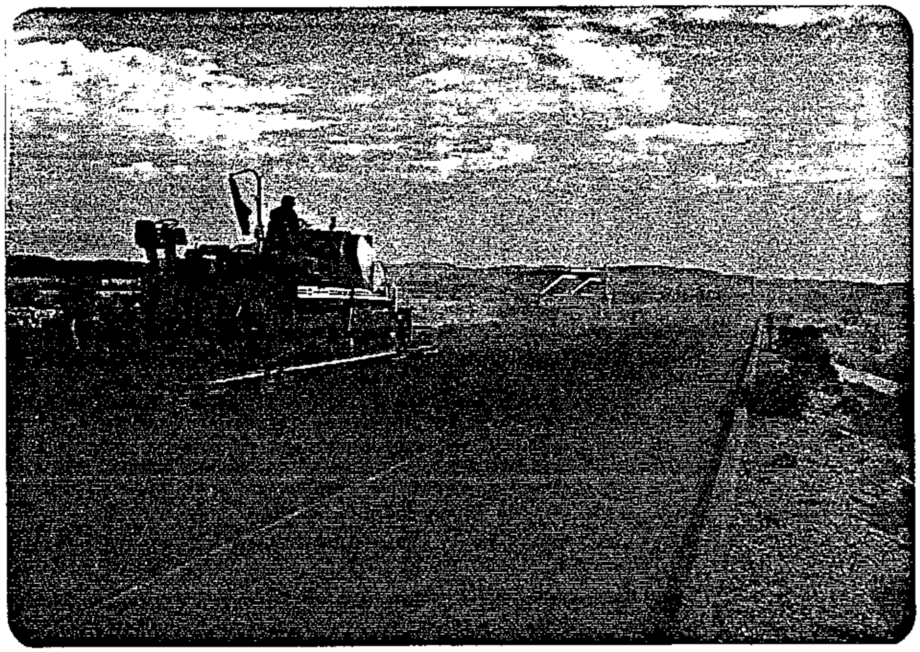
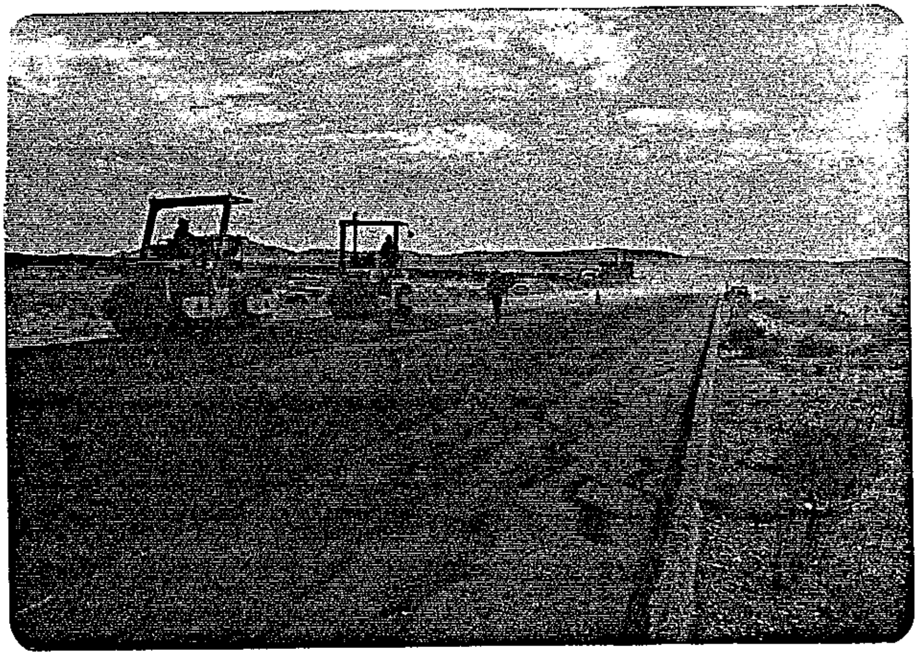


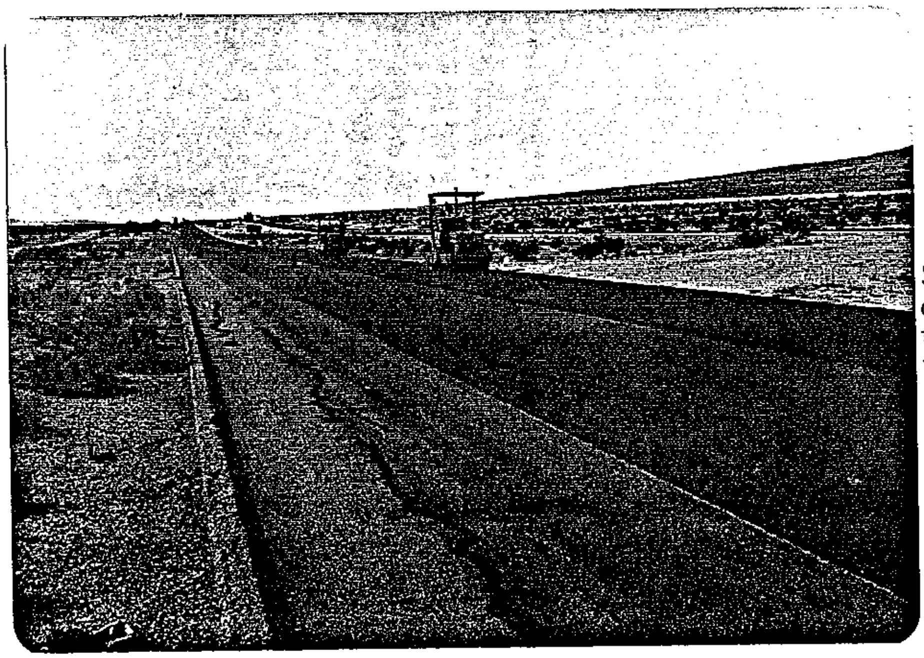
Figure 9

<u>SEA Paving Oper.</u>

Paving SEA 20% - 9-27-82
Note Sulfur cloud.



Rolling SEA 20% - Sulfur cloud activated whenever surface of mix is disturbed.



Sulfur cloud diminishes as the SEA surface is rolled.

TABLE 2

TOXICITY OF HYDROGEN SULFIDE AND SULFUR DIOXIDE

Hydrogen Sulfide (H_2S)*

Concentration (ppm)	Effect
>0.03	Odor detectable (rotten eggs).
3	Odor offensive, failure of sense of smell within a few minutes.
10	Threshold Level Value (TLV)-Time Weighted Average (TWA) (ACGIH).
15	TLV-STEL (Short-Term Exposure Limit) (ACGIH)
>20	Irritancy of eyes and respiratory tract which increases with concentration and exposure time.
200	Immediate failure of sense of smell.
300-500	Less than 1/2 hour exposure can result in headache, dizziness, staggering gait, nausea, and dryness and pain in the respiratory tract, (followed later by bronchitis and pulmonary edema).
>600	A few minutes exposure can be dangerous with increasing systemic and CNS involvement in addition to irritancy and edema.
1000-2000	Paralysis of the breathing centers can occur after a few breaths followed by collapse and quick death if removal to fresh air and restoral of breathing is not rapidly accomplished.

Sulfur Dioxide (SO_2)*

Concentration(ppm)	Effect
0.47	Detected by taste.
3-5	Noticable odor.
2	TLV-TWA (ACGIH)
5	TLV-STEL (ACGIH)
>6	Immediate irritation to nose and throat (sneezing and coughing).
20	Irritation to eyes, smarting and tearing.
50-100	Maximum Allowable Concentration for 30-60 minutes exposure, can be dangerous
400-500	Immediately dangerous to life.

*Data from:

1. Hydrogen Sulfide, Material Safety Data Sheet No. 52
   General Electric Co., Schenectady, NY (12-1979)

2. Sulfur Dioxide, Material Safety Data Sheet No. 50
   General Electric Co., Schenectady, NY (12-1979)

Detection Analyzer (ranges: 0-10/0-100 ppm)

b. SO_2 - Interscan Model 1248 Portable Gas Detection Analyzer with a H_2S dry scrubber (ranges: 0-10/0-25/0-50 ppm)

2. Long-term exposure device:

a. Draeger Polymeter with long duration tubes for H_2S and SO_2. Concentrations of each gas were determined individually.

3. Total Suspended Particulates (TSP) and Sulfates.

a. General Metals Hi-Volume Air Sampler with a Sierra Instruments Flow Controller which produced a steady air flow of 40 ft^3/minute.

Methods used to determine sulfates and free sulfur portions of TSP were as follows:

a. Sulfates: AIHL Method No. 61 on 1/4 of HiVol Filter (Turbidimetric Barium Sulfate).

b. Free Sulfur: AQAC method for Free Sulfur in Fertilizer (Modified), 11th Edition, 1970, page 31, par. 2.140.

The contract under which the SEA test section was placed called for the contractor to be responsible for meeting the California OSHA regulations in regard to concentrations of H_2S and SO_2 gases. The regulations are as follows:

1. Sulfur Dioxide (SO_2) (Register 80,

No. 32-8-9-80) Table AC-1, Chemical Contaminants: Permissible Exposure Limit for 8 hours (PEL): 5 ppm, 13 mg/M^3 (25C, 760 mm Hg).

2. Hydrogen Sulfide (H_2S) (Register 81, No. 41-10-10-81). Table AC-2, Excursion H_2S Exposures:

PEL (8 hrs)		Excursion	Excursion	Ceiling
ppm	mg/m^3(25C 760 mmHg)	Limit	Duration	Limit
10	15	20 ppm	10 minutes/8 hours	50 ppm

Authority: Cal-OSHA Title 8, California Administrative Code, General Industry Safety Order, Section 5155 (Airborne Contaminants),

Particulate levels and associated sulfate and free sulfur amounts were compared to worker environment limits set forth by Cal-OSHA Title 8 California Administrative Code, General Industry Safety Order, Section 5155, Register 81, No. 41-10-10-81 as follows:

Table AC-3

Permissible Exposure Limits (PEL) for Mineral Dusts

Substance	PEL (8 Hour) mppcf[(a)]	mg/m^3
Nuisance Particulates <1% quartz		
(total dust)	30	10
(respirable dust)		5

(a) Millions of particles per cubic foot of air based on impinger samples counted by light-field technics (mppcf x 35.5 = million particles per cubic meter or particles per cubic centimeter.)

For sulfur specifically, there is a Material Safety Data Sheet No. 56 with the following specifications: The nuisance dust TLV (Threshold Limit Value) should govern exposure to solid sulfur in the absence of other standards.

Measurements were made with the various apparatus during the SEA paving operations. The measuring locations, frequency, and results obtained are presented in Table 3. As can be determined from the data, the H_2S and SO_2 levels at no time or place exceeded the OSHA regulations either on a short- or long-term basis. These results generally agree with all other reported SEA projects where the mixing temperature was properly controlled. The particulate levels showed wide variation regarding TSP results, but the high readings at the plant were very much subject to the amount of wind-blown dust. Only on the day of high winds did the nuisance dust exceed the 10 mg/m^3 OSHA Standard. There was an increase in sulfates at the plant (over the levels measured during the AR-4000 AC paving and during a nonpaving day during a breakdown) and on the street during the SEA paving. Free sulfur levels at the plant site were slightly higher than the street location, but were still considered low in both locations.

None of the contractors or state personnel used any protective breathing equipment during the SEA paving operation. The main complaints were because of the smell.

TABLE 3

ENVIRONMENTAL SAMPLING RESULTS

Paving Material	Date	Weather Conditions	Temp. °F	Sampling Location	Short Duration (Interscan) H_2S ppm	Short Duration (Interscan) SO_2 ppm	Long Duration (Draeger) H_2S ppm	Long Duration (Draeger) SO_2 ppm	Particulates* (Hi-Vol air sampler) TSP mg/m^3	Particulates* (Hi-Vol air sampler) Sulfates mg/m^3	Particulates* (Hi-Vol air sampler) Free Sulfur mg/m^3
AR-4000 control	9-22-82	clear, calm	83-103	Plant					0.35 (4 hours)	0.0098	0
"	"	"	"	Street PM108.2 (Median)					0.07 (4 hours)	0.0066	0.00003
No Paving (stockpiling)	9-23-82	clear, windy	78-100	Plant					0.66 (3&1/2 hours)	0.0104	0
"	"	"	"	Street PM108.5 (Median)					0.12 (3&1/2 hours)	0.0112	0.00009
SEA 20% & 40%	9-27-82	Partly cloudy to Showers, Windy	68-77	Plant	0.3 (about 9AM)	0			13.64 (10 hours)	0.0465	0.0458
SEA 20%	"	"	"	Street (HVS-PM109.3 road side)	windrow 2-3 paver 3-4	0 0.5	1.38 (10-12AM) (Unit on Paver)	0.517 (2:30-4:30pm) (Unit on Paver)	0.11 (6 hours)	0.0246	0.0119
SEA 40%	"	"	"	"	windrow 2-3 paver 3-5	1 1					
SEA 20% & 40%	9-28-82	Clear, light wind	73-82	Plant					2.9 (7 hours)	0.0378	0.023
"	"	"	"	Street (HVS-PM109.7 road side)					0.08 (6 hours)	0.0175	0.0145

* Hi-Vol: General Metals High Volume air sampler.
TSP: Total Suspended Particulates.
Sulfates: determined by AIHL Method No. 61 (Turbidimetric Barium Sulfate)
Free Sulfur: determined by AOAC Method for free sulfur in fertilizer (modified) 11th Edition 1970 page 31, par. 2.140

The paving crew complained of nausea but none of them were absent for the second day of SEA paving. One truck driver and a flagperson (red hair, fair complexion) claimed that they broke out with a rash on their faces. It is not known if either sought medical attention. The results from Table 3 indicate that maintaining H_2S and SO_2 at a safe level should not be a problem.

POST INSTALLATION TESTING

I. Field Testing

Due to the remoteness of this test section, the field tests were performed whenever the testing crews could fit this work into their schedules. Therefore, there is some variation in the period of time after installation for each test.

A. Deflection Testing

The deflection tests were performed about five weeks after construction of the test sections. The results are presented in Table 4, which also lists some results of testing about 2 1/2 years prior to the test section installation. The prior and present results which indicate low deflections throughout the test area, should allow for a uniform evaluation of the test products.

B. Skid Resistance Testing

Generally, a new AC surface will have good skid resistance. These tests were performed to see if the presence of sulfur

TABLE 4

DEFLECTION DATA*

Section (thickness)	Test Section Location	Deflection Location	Deflection (inches) NB #1 Lane Mean Deflection	NB #1 Lane 80th Percentile	NB #2 Lane Mean Deflection	NB #2 Lane 80th Percentile
AR-4000 Control (0.25')	PM 107.75 to 108.25	PM 108.0 to 108.2	.004	.006	.005 (.006)**	.006 (.007)**
AR-2000 Control (0.25')	PM 108.25 to 108.96	PM 108.5 to 108.7	.007	.010	.008	.010
SEA 20% (0.25')	PM 108.96 to 109.48	PM 109.1 to 109.3	.004	.008		
(deficient binder area)	PM 108.96 to 109.15	PM 108.9 to 109.2			.008 (.008)** (PM109.0 to 109.2)	.012 (.013)**
	PM 109.15 to 109.58	PM 109.3 to 109.5			.010	.013
(SEA 20%) & SEA 40%)	PM 109.48 to 109.53	PM 109.45 to 109.55	.004	.007		
SEA 40% (0.25')	PM 109.53 to 109.94	PM 109.6 to 109.8	.004	.007		
	PM 109.58 to 109.94	PM 109.6 to PM 109.8			.009	.012

* Calif. Test 356-Dynaflect Deflections obtained 11-3-82 -- 5 weeks after installation

**Previous Deflection Data (2-20-80)

in an AC mix would affect skid resistance. Table 5 presents the results of skid resistance tests performed about 28 weeks after the construction of the test section. The results indicate no differences between the control sections and the SEA sections.

C. Pavement Roughness Measurements

The measurement data presented in Table 6 are known as ride score numbers. A ride score of 45 is considered by Caltrans to be grounds for pavement rehabilitation; thus, the test section pavements are providing uniform, very smooth rides.

D. Condition and Crack Surveys

The first postconstruction condition and crack mapping survey was performed when the test section pavements were approximately eleven months old. The surveys revealed that all of the test sections were in excellent condition, with no cracks evident in any of the test areas. Figures 10 and 11 are representative of the SEA sections.

Two additional condition and crack surveys were performed during February and July of 1984 (17 and 22 months after construction). These surveys also revealed no cracking in any of the SEA or control test sections. Table 7 contains the original and subsequent crack survey results for each section. Cracking, as reported in Table 7, is the total of any and all cracking per running foot, including longitudinal, transverse and block cracking.

TABLE 5

SKID TEST DATA (ASTM E-274)

Test Section	Location	Skid Number (ASTM SN_{40}) Lane #1 IWT	Lane #1 OWT	Lane #2 IWT	Lane #2 OWT
AR-4000	P.M. 107.75 to 108.25	47	52	48	47
AR-2000	P.M. 108.25 to 108.96	45	49	45	44
SEA 20%	P.M. 108.96 to 109.58	50	52	49	50
SEA 40%	P.M. 109.58 to 109.94	48	50	47	47

NOTES:

- o Tests performed 4-14-83, 28 weeks after installation
- o IWT = inside wheel track
- o OWT = outside wheel track

TABLE 6

RIDE SCORE TEST RESULTS* (50 MPH)

TEST SECTION	LOCATION	RIDE SCORE	
		Lane #1	Lane #2
AR-4000	PM 107.75	6	2
AR-2000	PM 108.25	7	2
SEA 20%	PM 108.96	11	4
SEA 40%	PM 109.58	7	4

* Obtained May, 1983, eight months after construction.

(A Ride Score reading of 45+ is considered a rough road. Readings were obtained with a Cox & Sons CS 8000 Ultrasonic Road Meter installed in a 1980 AMC Concord Sedan. The meter is a PCA response type road meter. Further information can be obtained from the California Pavement Management System Manual of Rating Instruction, (September, 1979), California Department of Transportation, Department of Maintenance, Sacramento, California).